DESIGN OF STATE OF ART LOW NOISE VCO USING MMIC NEGATIVE RESISTANCE MODULES

E. LAPORTE* - P. MAURIN** - J.C. NALLATAMBY*
D. REFFET** M. PRIGENT* - J. OBREGON*

*I.R.C.O.M.-U.A. C.N.R.S. N°356 - 7 rue Jules Vallès - 19100 BRIVE (FRANCE)
**THOMSON-CSF MICROELECTRONIQUE - 29 Av. Carnot - 91349 MASSY CEDEX (FRANCE)

ABSTRACT

In this paper we present the design, fabrication and measurement of a state of the art low noise 10 GHz MESFET VCO. The novel design method associated with modern C.A.D. tools yield oscillators with an excellent phase noise of -90 dBc/Hz at an offset of 100KHz, which is the best result published for a X band FET VCO, with an electrical tuning range of 10%. The output power of 15 dBm over the oscillation frequency range is obtained.

INTRODUCTION

Modern microwave systems require stable, low phase noise tunable oscillators with sufficient output power. Previous works on VCO have demonstrated their great potential [1],[2],[3]. Our work has consisted of the realization of non linear negative resistance modules in MMIC technology of THOMSON foundry. Frequency tuning is carried out by means of an external varactor diode also provided by THOMSON foundry to allow the realization of VCO in several tuning range by simply changing this varactor. This chip consists of a negative resistance module cascaded with a two stage amplifier. The MMIC negative resistance module with an external varactor is shown in figure 1.

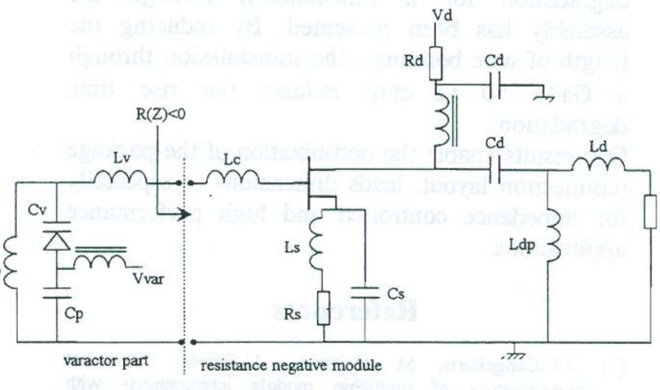

Figure 1 : VCO diagram

This circuit has been optimized using the following design method. It consists in three key points. The first is an open loop linear analysis of the oscillator which, for a given topology, allows to optimize the oscillator group delay in the tuning bandwith to ensure low phase noise and tuning range. The second analysis is a whole non linear analysis, using harmonic balance software, to finely tune the desired oscillation characteristics (power, oscillation frequency range,...). At last, a non linear noise analysis is performed to predict and adjust the bias point to minimize the phase noise spectrum using transistor low frequency noise model.

An autonomous transistor oscillator circuit is a closed loop formed by loading an active two-port transistor with a passive circuit which includes the output load G_u and the varactor (Fig 2).

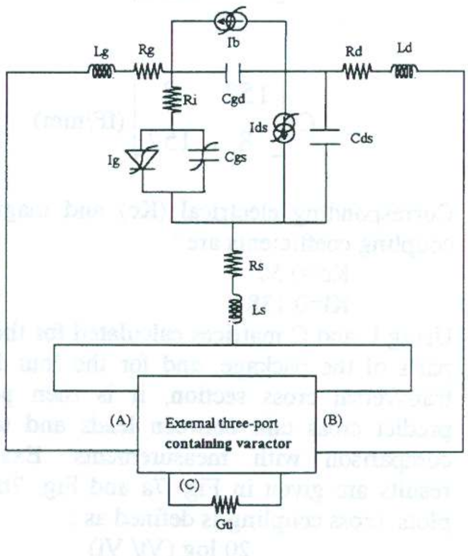

Figure 2 : MESFET oscillator diagram with the transistor non linear model

LINEAR OPTIMIZATION OF THE OSCILLATOR CIRCUIT

The key point of this method consists of opening the loop in the drain current source so that the drain current source is now controlled by the voltage V_{gs1} provided by the external voltage E_g and by its V_{ds} voltage, resulting in a stable amplifier configuration (Fig. 3).

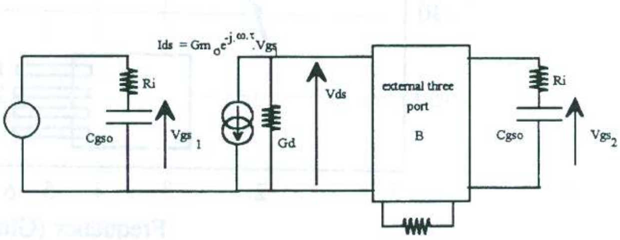

Figure 3 : Open loop linearized oscillator

Then, a linear optimization of the circuit elements included in the black boxe B may be performed with the following goals:

- in order to maximize the group delay, over the desired oscillation frequency range to minimize phase noise. The Figure 4 shows this groupe delay versus the frequency tuning range.

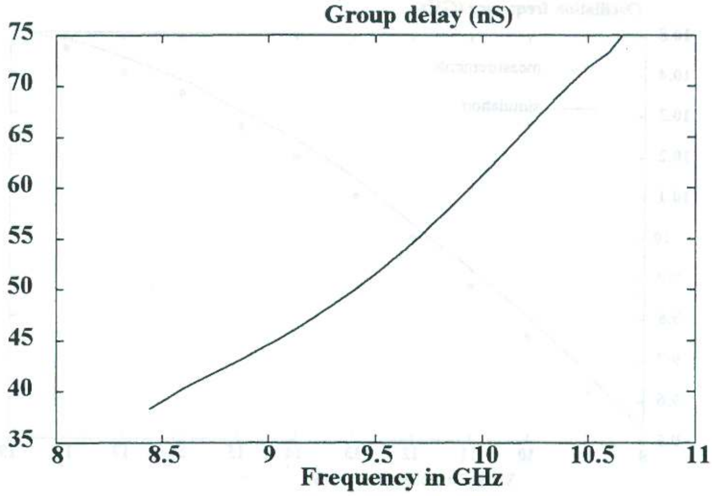

Figure 4 : Group delay over the frequency tuning range

- in order to obtain a ratio $\frac{V_{gs_2}(\omega_0)}{V_{gs_1}(\omega_0)}$ with a module greater than one and a phase close to zero, because, when the circuit oscillates, this module will tend to one with null phase.

- in order to obtain $\Re(Z) < 0$ at the input of a negative resistance module versus the frequency tuning range. The input impedance of the linearized negative module is shown in figure 5

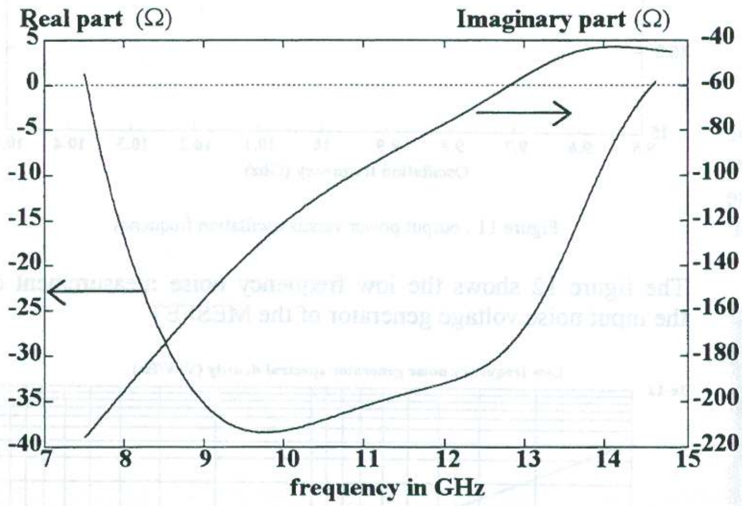

Figure 5: Real and imaginary part of negative resistance module input impedance.

NON LINEAR ANALYSIS

To perform the non linear analysis, the conventionnal MESFET non linear model is replaced in the oscillator diagram of figure 2 to obtain the diagram of figure 6.

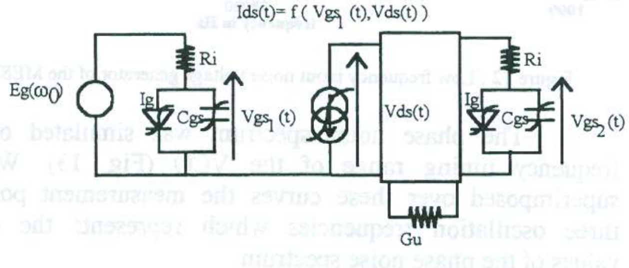

Figure 6: Non linear diagram of open loop oscillator

This open loop analysis non linear method is detailled in reference [4]. The goal of this analysis is to find a sufficient Eg level and a ω_0 pulsation of the generator such as the $Vgs_1(t)$ and $Vgs_2(t)$ are exactly the same ones over the frequency range. With these conditions the oscillation is obtained when the circuit is fedback. Figure 7 shows these two voltages for a frequency in the tuning range (a) and out of the tuning range (b) for a same generator level.

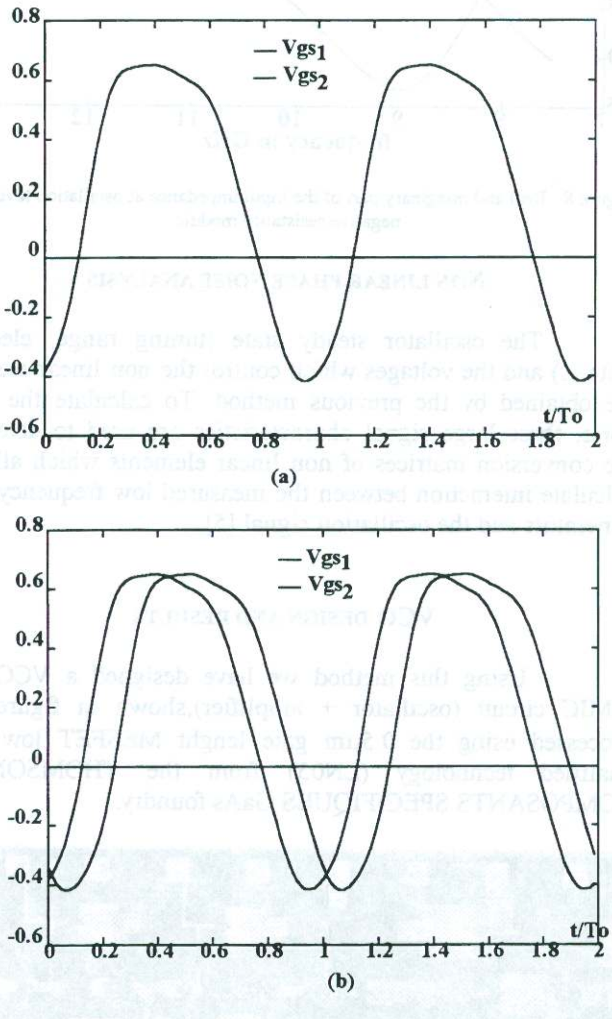

Figure 7: Gate voltage waveforms

Then a closed loop analysis allows to verify these oscillation conditions. The real and imaginary part of the input impedance at oscillation level of the negative resistance module are shown in Figure 8.

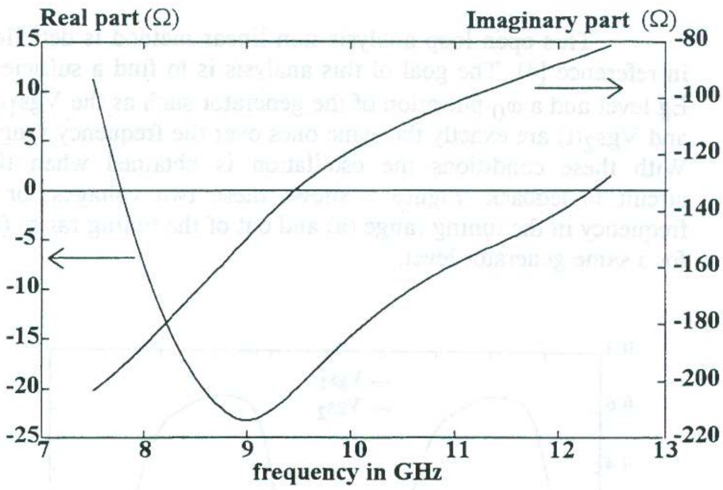

Figure 8 : Real and imaginary part of the input impedance at oscillation level of the negative resistance module

NON LINEAR PHASE NOISE ANALYSIS

The oscillator steady state (tuning range, electrical state,...) and the voltages which control the non linear elements are obtained by the previous method. To calculate the phase noise, these large signal characteristics are used to determine the conversion matrices of non linear elements which allow to calculate interaction between the measured low frequency noise generators and the oscillation signal [5].

VCO DESIGN AND RESULTS

Using this method we have designed a VCO. The MMIC circuit (oscillator + amplifier),shown in figure 9 is processed using the 0.5µm gate lenght MESFET low noise qualified technology (LN05) from the THOMSON-CSF COMPOSANTS SPECIFIQUES GaAs foundry.

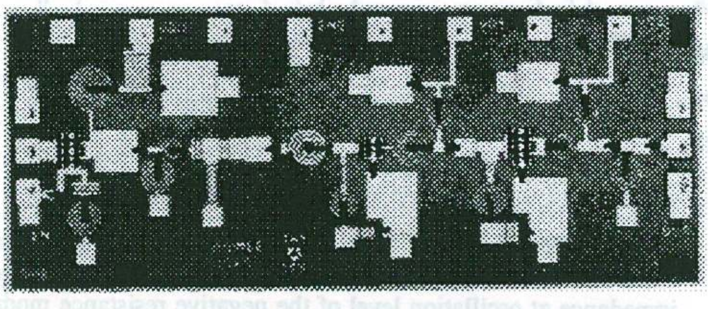

Figure 9 : MMIC VCO and amplifier circuit

Main characteristics of this process are ion-implanted active layers, TiPtAu 0.5µm Ebeam defined gates, implanted TaN resistors, Si_3N_4 overlay capacitors, spirals inductors, air bridges and via holes through 100µm thick wafer. The circuit chip size is 1.1x2.6 mm². The MESFET used in the oscillator circuit have 4x75 µm gate width and it is biaised at Vgs=-0.3V and Vds=3.5V . The double stage linear amplifier is resistively matched and gain optimized in the 8-12GHz range. The MESFET have 2x75 µm and 4x75 µm for the first and second stages. In the following curves we present the simulation and measurement results: oscillation frequency versus varactor voltage (figure 10) and output power versus oscillation frequency (figure 11)

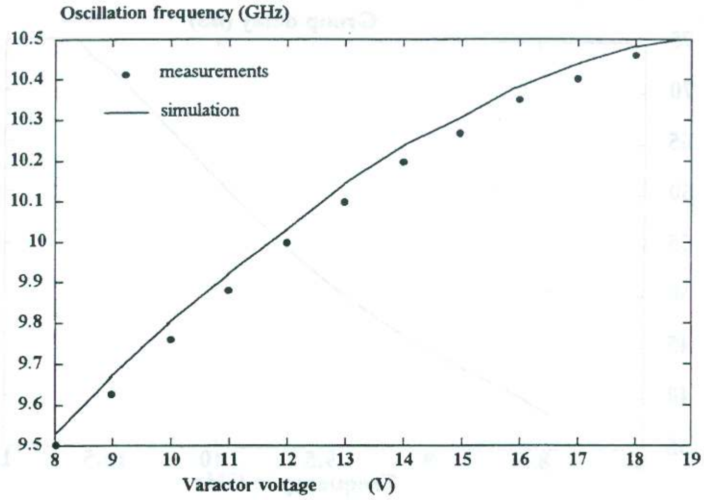

Figure 10 : oscillation frequency versus varactor voltage

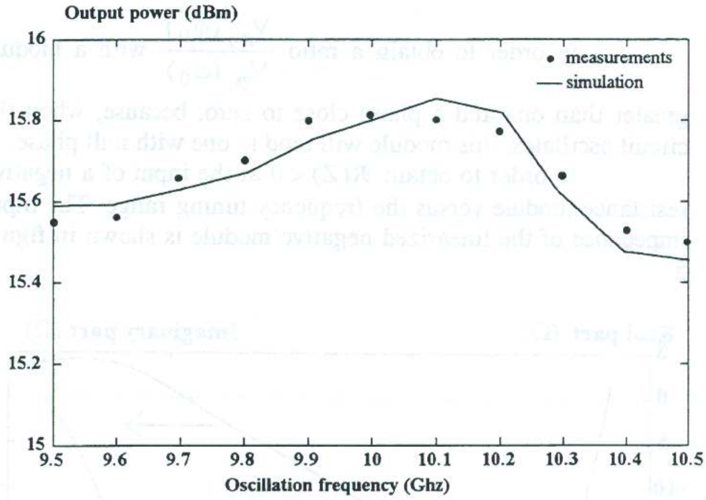

Figure 11 : output power versus oscillation frequency

The figure 12 shows the low frequency noise measurement of the input noise voltage generator of the MESFET.

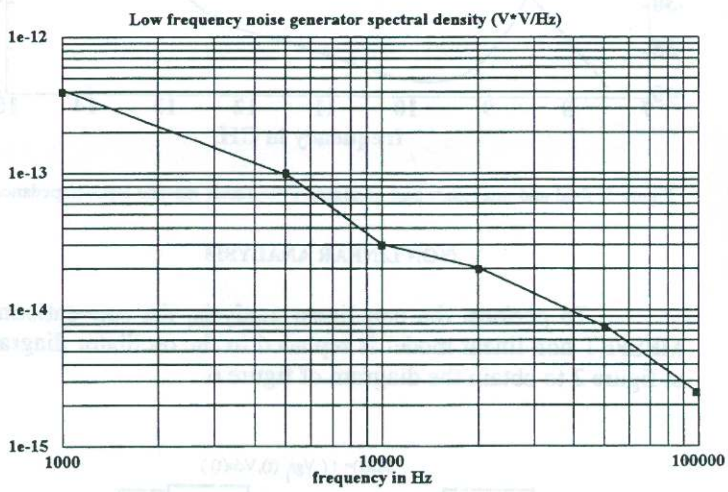

Figure 12 : Low frequency input noise voltage generator of the MESFET

The phase noise spectrum was simulated over the frequency tuning range of the VCO (Fig. 13). We have superimposed over these curves the measurement points for three oscillation frequencies which represents the extreme values of the phase noise spectrum.

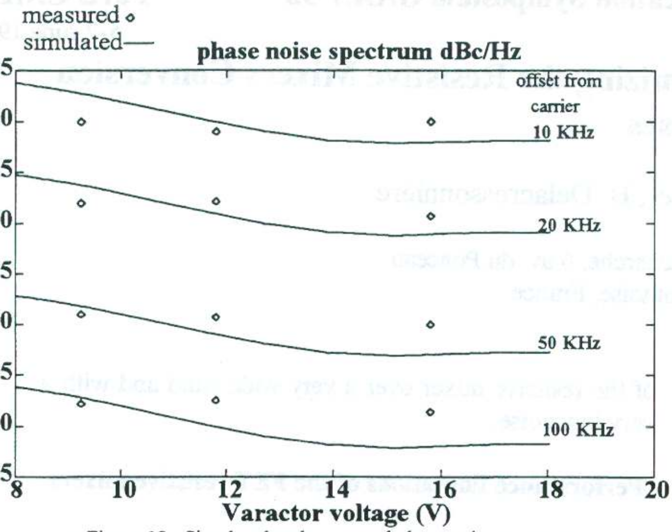

Figure 13 : Simulated and measured phase noise spectrum

The discrepancy between these measured and simulated results comes from an inaccuracy noise model of the transistor. In fact, the noise generators must be placed into the non-linear transistor where the noise conversion takes place. So, we are developping a new distributed non-linear model of MESFET [6] in which we have placed the low frequency noise generators Ign_1, Ign_2, Ign_3, Idn_1, Idn_2 as shown in Figure 14. These generators may be cyclo-stationary and their spectral densities to depend on the oscillating voltages.

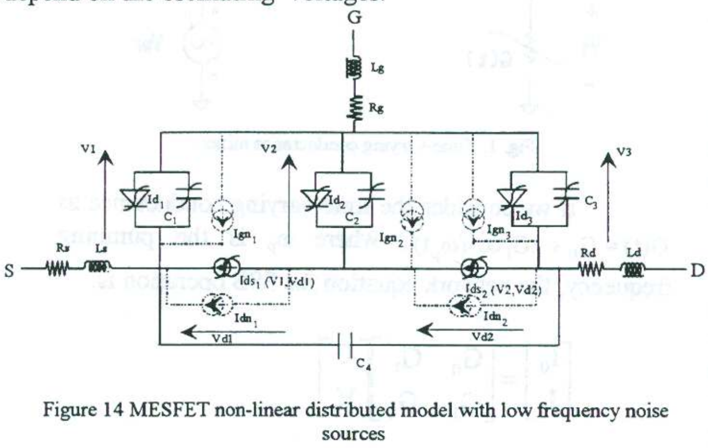

Figure 14 MESFET non-linear distributed model with low frequency noise sources

The non-linear model is now extracted [6],[7] and a new measurement procedure to extract the low frequency noise generators is in progress.

CONCLUSION

Modern microwave applications will require low phase noise sources operating in X band. A varactor tuned oscillator was designed using a new design approach. Compared to the conventionnal technique, the expertness of the non linear state of the oscillator is the goal of an optimization and not the result of an analysis. This method has permit us to obtain a excellent reproducible phase noise spectrum of -90 dBc/Hz at an offset of 100KHz for an oscillation frequency of 10 GHz and this method can be applied to the design of DRO and HBT MMIC VCO.

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